#6 1-15-2

SILICON NITRIDE WINDOW FOR MICROSAMPLING DEVICE AND METHOD OF CONSTRUCTION

by

Wilson Harvey Smart

Kumar Subramanian and

Asikeh S. Kanu

TECHNICAL FIELD

This invention relates generally to a window constructed of silicon nitride, and more particularly to a cuvette window of a microsampling device and a method of construction.

BACKGROUND

Diabetes mellitus is an insidious disease which affects more than 15 million Americans. About 1.5 million of these are Type I diabetics (insulin-dependent) and 12 to 14 million are Type II diabetics (noninsulin-dependent). The characteristics of diabetes include chronic and persistently high levels of glucose in blood and in urine. Although urine glucose has been used to monitor glucose levels, the measurement of blood glucose is more reliable and logistically feasible. Blood glucose has therefore become the most commonly followed clinical marker for monitoring the progress of diabetes (and other diseases) to determine treatment and control protocols. Glucose levels are routinely measured in doctors' offices, clinical laboratories, and hospitals. However, the most convenient and important measuring is in-home self-monitoring of blood glucose levels by the patients themselves to permit adjustment of the quantities of insulin and hypoglycemics administered.

There are many products for diabetes related testing of glucose for diagnostic and monitoring purposes. Most of the currently available technologies, especially for self-monitored blood glucose measurements, are not satisfactory because they require some kind of deep lancing or finger stick with associated pain and sometimes excessive bleeding.

The smallest lancet or needle currently marketed for blood sampling has a diameter between 300 micrometers and 500 micrometers, and is constructed of stainless steel with beveled edges. Due to the large cross-section of these lancets, fingertip lancing is painful and frequent lancing causes calluses, impairment of the use of hands, psychological trauma and other unpleasant consequences. Further, blood samples recovered from the patient must be transferred to a test strip or cartridge for assaying analyte concentrations. Obtaining blood samples by lancing and performing the analysis can be messy as well as painful for the patient.

U.S. Pat. No. 5,801,057, "Microsampling Device and Method of Construction," issued September 1, 1998, to Wilson H. Smart and Kumar Subramanian, describes a self-contained microsampling device and method for the measurement of glucose and other analytes in blood. Blood is drawn through a microneedle sufficiently small that the sampling is virtually painless into an integrated microcuvette where the analyte concentration is measured. The microsampling device of Smart et al has two windows, namely, a glass film for one window and a glass wafer for the other window. While these windows provide excellent transparency and functionality, the application of semiconductor processing to glass is less well established than is the case for silicon nitride. A silicon nitride cuvette window can be directly integrated with the other components of the microsampling device using standard semiconductor processing.

Unsupported silicon nitride films are used as membranes in products such as condenser microphones and pressure sensors. Supported films are used in electronics applications. In Yoo et al, U.S. Patent Nos. 5,578,517 and 5,729,041, a silicon nitride film is used to form a transparent window covering a fusible link. The window is fully supported on the fusible link or other substrate materials, however. Further, the window is not used to permit optical measurements but rather to permit laser irradiation of the fusible link.

SUMMARY

There still exists a need for simplification in the manufacturing process of a microsampling device which provides reliable and accurate measurements of glucose and other analytes. Furthermore, there still exists a need for a chamber (cuvette) window for such microsampling device which can be fabricated by standard semiconductor processing methods, which is able to withstand normal handling, and which is transparent to light in the desired visible regions, permitting accurate optical measurements. A microsampling device with microneedle and sampling chamber or cuvette fabricated wholly out of silicon with silicon nitride windows can be manufactured by standard semiconductor processing methods with precision and accuracy and at low unit cost.

It is an object of this invention, therefore, to provide a cuvette window of a microsampling device which is economical to fabricate, transparent at visible wavelengths, and able to withstand normal handling, and a process for its construction.

It is a further object of this invention is to provide a cuvette window of a microsampling device, formed by a silicon nitride film deposited on the microsampler chamber of the microsampling device with the film being exposed on both surfaces.

Supported silicon nitride films are widely used in semiconductor processing, primarily for masking. In order to use an unsupported film as an optical window, its deposition must be carefully controlled to produce a low stress film. This is a standard procedure in the optics industry, where the deposition of optical coatings is closely monitored to control variations in optical properties. Stress in silicon nitride films is decreased in two ways. First, the stoichiometric ratio of the silicon nitride composition is chosen to provide as close a match as possible to the coefficient of expansion of the silicon substrate. Second, plasma enhanced deposition is used. Optionally, application of an antireflective coating such as magnesium fluoride on the silicon nitride film will further improve the optics of these windows, permitting their use for optically read assays without contributing any significant error to the assay result.

It is a further object of this invention to provide a method of constructing a cuvette window for a microsampling device. The method utilizes standard semiconductor processes, permitting the window to be readily integrated into the fabrication of other microsampler components.

It is a further object of this invention is to provide a window of a silicon sampling chamber or cuvette, formed by a silicon nitride film deposited on the chamber of the cuvette with the film being exposed on both surfaces.

The silicon cuvette with silicon nitride window can be used for measurement of analytes other than blood or fluids accessed through the microneedle of the microsampling device. These analytes can be introduced thorough a vent or directly into the cuvette. Further, silicon nitride film windows as large as approximately 1 square centimeter can be fabricated with satisfactory handling and optical characteristics, thus permitting

semiconductor technology to be used to fabricate cuvettes with integrated silicon nitride windows which can be larger than the chamber of the microsampling device.

It is a further object of this invention to provide a method of constructing a window for a sampling chamber or cuvette fabricated of silicon. The method utilizes standard semiconductor processes, permitting the window construction to be readily integrated into the processes used to fabricate the cuvette.

Briefly, these and other objects of the present invention are accomplished by providing a cuvette window for a microsampling device and method for its construction. The cuvette window comprises a silicon nitride film deposited in a microsampler chamber etched into the surface of the silicon wafer, with a portion of the film being exposed on both sides. The silicon nitride window so formed can be fabricated by standard semiconductor processing methods, is able to withstand normal handling, and transmits light in the visible region.

BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1A is a section view of a silicon wafer prior to initial patterning and etching;

FIG. 1B is a section view of the silicon wafer of **FIG. 1A** subsequent to etching of the top surface to define the sampling chamber;

FIG. 1C is a section view of the silicon wafer of **FIG. 1B** showing a silicon nitride film layer deposited on the top of the etched wafer;

FIG. 1D is a section view of the silicon wafer of **FIG. 1C** with deposited silicon nitride film subsequent to etching the bottom of the wafer to remove the silicon in the window region and expose the bottom of the silicon nitride film;

FIG. 2A is a top view of microsampling device **20**;

FIG. 2B is a sectional side view of device **20** of **FIG. 2A** across lines IIB-IIB, showing sample chamber **20C** and chamber window **24W**; and

FIG. 2C is a sectional end view of device **20** of **FIG. 2A** across lines IIC-IIC.

DETAILED DESCRIPTION OF THE PREFERRED EMBODIMENTS

The present invention comprises a process of constructing a cuvette window for a microsampling device for the measurement of biological materials from biological fluids. The microsampling device is preferably fabricated from a silicon wafer and is generally described in U.S. Patent No. 5,801,057, by Smart et al, the subject matter of which is hereby incorporated by reference in its entirety into this disclosure. The present invention has a transparent window on the silicon wafer to facilitate optical readouts of the specimen within the cuvette. Optical quality silicon nitride film is deposited on the silicon wafer and silicon removed such that a portion of the film is exposed on both sides.

The microsampling device or microsampler has a very fine, short needle through which blood or other body fluids can be drawn into a small sampling chamber or microcuvette. Preferably, the microcuvette has a volume of less than one microliter. The microcuvette has at least one optical window and a vent to allow air to escape as the microcuvette fills when blood or other fluids are drawn in through the needle. The needle preferably has an outer diameter of 100 to 200 micrometers.

The microsampler is constructed using well-established silicon microfabrication technology which has been in wide use for decades for the manufacture of electronic integrated circuits and more recently has been extended to micromechanical devices. The microsampler is

made by a series of very precise photolithographic, etching and very precise microdeposition steps performed on a silicon wafer. A large number of the present microsampling device can be made at the same time on a single wafer, followed by dicing to separate the individual devices, each of which is commonly referred to as a die or chip in the microelectronics industry.

The cuvette window comprises a silicon nitride film formed on the microsampler chamber of the microsampler device with the window being exposed on two surfaces. The method of construction comprises providing a silicon wafer having a top surface **11S** (sampling side) and a bottom surface **11v** (viewing side), etching a patterned depression in the top surface of the silicon wafer thereby defining the microsampler chamber, depositing a silicon nitride film on the top surface of the silicon wafer, and etching a patterned depression in the bottom surface of the silicon wafer such that at least a portion of the silicon nitride film deposited in the microsampler chamber becomes exposed on both surfaces.

The stages or steps of the cuvette window fabrication process are illustrated in **FIGS. 1A-1D**, and are described in further detail below. The microsampling device may have one or two cuvette windows, depending on the detection method used. A two window device suitable for analyze detection using transmittance photometry can be fabricated from two wafers where the cuvettes and windows are bonded together in registration. Alternately, the second window can be provided separately in the device holder. A microsampling device with only one cuvette window is used where the methods of choice for the detection of the analyte may be fluorescence, luminescence, or reflectance photometry. In this case, a blank silicon wafer is bonded to the wafer containing the cuvettes and windows, and the individual devices then separated.

In the present example, a silicon wafer about 500 micrometers thick having one surface polished forms silicon substrate **10a** of the microsampling device as illustrated in **FIG. 1A**. Silicon wafers of this type are commercially available and are commonly used in the integrated circuit industry in thickness of 500 to 1000 micrometers.

Silicon substrate **10a** is first patterned and plasma etched on the top polished surface to form the vent, cuvette, and needle bore pattern required for operation of the microsampling device. **FIG. 1B** illustrates the microsampler chamber or cuvette in silicon substrate **10b** subsequent to the plasma etching. As illustrated in **FIG. 1C**, low stress silicon nitride film **12c** is then deposited onto the top surface of silicon substrate **10c**. The silicon nitride film has a thickness of approximately 0.01 to 5 micrometers.

As illustrated in **FIG. 1D,** the bottom of silicon wafer **10d** is then etched with a potassium hydroxide wet etchant to remove silicon and expose the bottom of silicon nitride window **12d**.

Microsampling device **20** for obtaining a microsample of bodily fluid from a subject, is shown in **FIG.s 2A, 2B, and 2C**. Silicon substrate **20S** has chamber **20C** with sampling side **21S** and viewing side **21V** for containing and viewing the microsample (not shown). Chamber window **24W** formed of silicon nitride covers the chamber for closing the viewing side thereof. The silicon substrate may have a thickness of about 500 micrometers, and the silicon nitride window may have a thickness of from about 0.01 of a micrometer to about 5 micrometers. The silicon nitride forming the window is preferably of optical quality. An antireflective coating of a suitable material such as magnesium fluoride may be provided the silicon nitride window. Closure member **24C** may be provided over the chamber for closing the sampling side. The closure member

engages the substrate around the periphery of the chamber forming an interface therebetween. Needle **26N** formed at needle end **26** of the device may be provided for obtaining the sample. Intake bore **26B** for transporting the sample into the chamber, extends from the needle end to the chamber along the interface between the closure member and the substrate. Exhaust vent **26V** for venting the chamber as the sample is transported into the chamber, extends from the chamber away from the needle end along the interface between the closure member and the substrate. The bore and/or the vent may be formed in the substrate.

INDUSTRIAL APPLICABILITY

It will be apparent to those skilled in the art that the objects of this invention have been achieved as described hereinbefore by providing a silicon nitride cuvette window for a microsampling device. The silicon nitride window provides at least three advantages. First, the cuvette window can be fabricated by standard semiconductor processing methods. Second, the cuvette window is substantially transparent in the desired wavelengths. Finally, the cuvette window withstands normal handling in course of using the microsampling device.